This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

With the Compliments of
WM. RIPLEY NICHOLS.

[From the Proceedings of the Boston Society of Natural History,
Vol. XXI, Oct. 6, 1880.]

ON THE TEMPERATURE
OF
FRESH-WATER LAKES AND PONDS.

BY

PROFESSOR WM. RIPLEY NICHOLS,
OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

BOSTON:
PRESS OF WM. H. WHEELER.
1881.

~~X 836~~
Eng 1078.81.3

1881, Dec. 10.
[illegible]

[From the Proceedings of the Boston Society of Natural History,
Vol. XXI, October 6, 1880.]

ON THE TEMPERATURE OF FRESH-WATER PONDS AND LAKES.

BY WM. RIPLEY NICHOLS.

Sometime since I had reasons for wishing to know the facts with reference to the temperature, at different depths, and at different seasons, of the rather shallow fresh-water ponds and lakes such as are used in this part of the country as sources of water-supply. I was not at that time able to find any series of observations which answered my purpose, and was, consequently, led to make some observations on the ponds in this neighborhood.

I was also led to search rather carefully for what might have already been published on the general subject of the temperature of ponds and lakes. I shall append to this communication a list of such published papers as I have been able to meet with, but these, in most instances, are the results of isolated or rather infrequent observations, or, if there is a daily record, it is almost invariably of the surface water alone. Besides that which has been published, I am aware that observations are made in various cities and towns on the water used for the general supply, sometimes at its source, sometimes as it issues from the conduit, and sometimes in the pump-well of the water-works. These observations, if published at all, appear in local reports not readily accessible, and they are, indeed, seldom published in detail.

The points on which I particularly desired information were:— (1) the difference in temperature at different seasons between the top and bottom water of the various ponds, (2) the rate and manner of the progressive cooling of the water in the fall and of the warming up in the spring, and (3) the extent to which the temperature is lowered in winter.

The first pond chosen for examination was Fresh Pond. This pond covers an area of some two hundred acres, and serves as the source of water-supply of Cambridge, Mass. It is fed mainly by the ground-water or by actual springs. The present observations were made at the entrance to the bay from which there is pumped, for city supply, from two and a quarter to two and a half million gallons per day on the average. The water at this part of the pond is, as a rule, from thirty-five to forty feet deep. The observations were made at three depths; one as near the bottom as possible, one at twenty feet from the surface, and one at two feet from the surface; no great stress is laid, however, upon the latter observation, as the surface temperature may, in the case of a small pond, vary to the extent of several degrees, during the same day, and at different points on the pond. The results are presented in the table on the opposite page.[1] (Table I.)

Another pond on which more or less frequent observations of temperature have been made, is Mystic Pond, from which a portion of the City of Boston is supplied. Mystic Pond (or Lake) covers in all a flowage area of some two hundred and thirty acres and derives a considerable portion of its supply from surface water, namely from the Abajonna River. The deeper portion of the pond — the original pond, in fact — forms a basin of from one hundred to one hundred and twenty-five acres extent and is, in some places, of considerable depth. The point at which the observations were made was well out into the pond, say one thousand feet from the shore and about one-half a mile from the

---

[1] These observations in Fresh Pond, in connection with the results of chemical examinations, were presented at the Saratoga meeting of the American Association for the Advancement of Science, August, 1879, and published in the First Annual Report of the Mass. State Board of Health (1880), pp. 97-107. As the Board of Health Reports have a limited circulation among other than sanitarians, I have taken the liberty of communicating the results to this Society.

TABLE I. OBSERVATIONS OF TEMPERATURE IN FRESH POND, MASS.

Date.	Height of Water in Pond above Cambridge Datum.	Temperature (expressed in centigrade degrees) at		
		Two feet from surface.	Eighteen feet from surface.	Thirty-five feet more or less from surface.
	Feet.	°	°	°
May 4, 1878	16.40	16.5	12.5	8.5
“ 14,	—	14.5	14.5	8.5
June 4,	16.11	19.	16.5	8.8
“ 12,	15.68	17.3	16.8	8.6
“ 19,	15.38	20.5	16.8	8.7
“ 25,	15.30	22.2	16.6	9.2
July 2,	14.99	28.0	16.7	9.3
“ 9,	14.57	26.0	16.4	9.2
“ 16,	14.60	25.8	16.8	9.6
“ 23,	14.38	24.0	16.8	9.9
Aug. 6,	14.25	24.0	17.3	10.1
“ 13,	14.75	24.0	20.1	10.0
“ 20,	14.67	24.0	20.0	10.2
“ 27,	14.54	22.3	20.0	10.0
Nov. 7,	13.66	9.5	9.2	8.7
Dec. 7,	14.50	4.5	4.3	4.5
Jan. 2, 1879	14.78	0.5	1.0	1.0
“ 14,	14.68	0.7	1.3	1.7
“ 22,	14.58	0.9	2.0	1.8
April 14,	15.16	6.0	5.0	4.4
May 13,	15.46	18.5	13.0	8.3

gate-house; at this point the water was from seventy-five to eighty feet deep.

During the greater part of the time a buoy moored in the pond has enabled us to identify the station and to take the samples in a nearly vertical line one above the other, but during a part of the time the position has been reached only approximately, and the observations have been made from an unmoored boat. The results of the various observations are recorded in Table II, and are shown in the accompanying diagram, Plate I, together with the daily mean temperature as reported by the U. S. Signal Service observer in Boston, and the daily observations of temperature made by the engineer at the pumping station of the water-works, to which the water flows from the pond by a closed conduit

TABLE II. OBSERVATIONS ON MYSTIC LAKE.

[Temperatures expressed in centigrade degrees.]

Date.	Daily Mean Temperature at Boston.	Temperature of air at time of observation.	Temperature in Pump-well of Water-works.	2 feet from surface.	18—20 ft. fm. surf'e.	36 feet fr. surface.	50—55 feet from surface.	70—75 feet from surface.	Approx. depth at point of observat'n.	Height of water in Lake in gate house in feet.[1]
October 18, 1879,	16.8	19.0	16.7	16.5	16.3	6.8[3]	—	6.8	72	2.24
November 5,	—2.8	5.3	8.1	7.8	7.9	—	—	6.0[2]	65	1.85
" 8,	9.4	—	7.2	7.3	7.8	—	6.8	—	55	1.80
" 15,	18.8	18.8	8.8	9.5	8.8	—	—	6.8[2]	65	1.13
" 22,	—4.6	—0.2	6.1	6.7	6.3	—	6.0	—	55	1.07
December 3,	5.7	6.4	5.0	4.9	4.9	—	—	4.9	75	0.87
" 12,	0.9	2.4	5.0	4.9	5.2	—	—	5.0	75	0.95
" 19,	—3.8	1.6	3.6	3.0	3.7	—	—	3.9	80	1.71
" 23,[5]	—1.8	—	1.4	—	—	—	—	—	—	1.67
January 30, 1880,[6]	1.5	—	2.5	2.5	2.8	—	—	2.8	75	6.22
February 6,[6]	—2.1	—	1.7	1.2	2.6	—	—	3.2	75	6.31
" 17,[6]	6.7	—	1.4	0.9	2.8	—	—	3.0	75	6.20
" 18,[7]	11.9	11.0	1.4	1.9	2.8	—	—	3.1	75	6.10
" "	11.9	11.0	1.4	2.4[4]	2.8	2.8[3]	—	2.8[2]	64	6.10
" "	11.9	11.0	1.4	—	2.8	2.8[3]	—	—	42	6.10
" "	11.9	11.0	1.4	2.1[4]	—	—	—	—	30	6.10
" 27,[8]	9.0	5.6	2.2	2.4	—	—	—	—	—	6.03
March 2,[9]	0.7	2.0	2.5	2.6	—	3.0	—	—	40	6.15
" 6,	0.8	6.4	3.3	4.1	4.0	—	—	4.0	75	6.16
" 10,[12]	—1.4	0.2	3.0	3.4	3.6	—	—	3.8	75	5.99
" 13,	—4.7	—4.5	2.5	2.9	3.0	—	—	3.2	75	5.96
" 24,[13]	—2.1	3.4	3.3	3.6	3.6	—	—	3·7[2]	68	6.08
" 27,	—0.6	3.6	2.5	2.9	3.0	—	—	3.2	75	5.82
April 5,	11.4	9.4	4.6	4 8	4.8	—	—	4.9	75	6.28
" 13,	10.7	15·0	5.6	6.3	6.2	—	—	6.1	75	5.88
" 14,	5.7	13.9	6.1	7.2	6.6	—	—	6.1	75	5.95
" 17,	2.3	5.3	7.2	7.2	7.2	—	—	6.2	75	5.26
May 3,	18.3	25.0	10.0	10.9	10.7	—	—	6.7	75	6.52
" 12,	16.2	21.1	17.8	18.5	12.8	—	—	6.7	75	6.26
" 15,	11.5	15.6	15.6	16.1	14.8	9.6	7.4	6.8	75	6.25
" 24,	24.6	30.0	18.9	21.0	15.9	—	—	6.9	75	6.20
June 3,	14.3	—	20.3	20.9	19.0	9.2	7.4	6.9	75	5.58
" 18,	19.7	—	22.8	22.7	18.2	—	—	7.2	75	4.64
" 25,	25.3	—	23.1	24.3	19.2	—	—	8.3	75	3.97

---

[1] High water is 7.00.

[2] At 60—65 feet from surface.

[3] At 40 feet from surface.

[4] At 6 feet from surface.

[5] Ice formed on the night of Dec. 22-23.

[6] Pond covered with ice.

[7] Ice melting rapidly.

[8] Pond about one-quarter open. Observation made at gate-house.

[9] Ice broke up March 1; much drift ice at date.

[12] Thin ice at edges of pond.

[13] Thin ice formed last night; all gone at 10 A.M.

about a mile and a half in length. For these latter figures, which are given in full in Table III, I am indebted to the City Engineer. These observations, as well as those of the U. S. Signal Service, are made in Fahrenheit degrees, but I have calculated them into the degrees of the centigrade scale.

TABLE III. OBSERVATIONS MADE AT THE PUMP-WELL OF MYSTIC WATER-WORKS.

[Temperature expressed in degrees centigrade.]

Day of Month.	1879. Oct.	Nov.	Dec.	1880. Jan.	Feb.	March.	April.	May.	1880. June.
1		10.6	4.7	2.2	2.5	2.8	3.0	10.0	20.8
2		9.5	4.7	1.9	2.2	2.5	3.0	10.0	21.1
3		9.5	4.7	1.9	2.5	2.5	3.3	10.0	20.3
4		9.2	4.7	1.9	2.2	2.8	3.3	10.6	20.3
5		8.1	3.7	2.2	2.2	3.3	4.5	13.3	20.0
6		7.5	5.7	2.2	1.7	3.3	6.1	13.3	20.0
7		7.2	4.7	2.2	1.7	3.9	6.1	13.6	19.7
8		7.2	5.0	2.2	1.7	3.6	5.3	13.6	19.7
9		6.9	4.7	2.2	1.7	3.3	5.3	13.9	18.9
10		7.8	4.5	2.2	1.7	3.0	5.3	16.7	18.6
11		8.1	4.7	2.2	1.9	3.3	5.6	16.4	18.9
12		7.5	5.0	2.5	1.7	2.8	5.6	17.8	18.9
13		8.3	4.5	2.5	1.7	2.5	5.6	17.5	22.2
14		8.1	4.5	2.2	1.7	2.8	6.1	16.1	22.5
15		8.3	4.5	2.2	1.7	2.8	6.9	15.6	22.2
16		8.9	4.2	2.2	1.4	2.8	7.2	15.3	22.2
17		8.6	4.2	2.2	1.4	2.5	7.2	15.3	22.2
18	16.7	8.6	3.6	2.2	1.4	2.2	6.9	16.1	22.8
19	16.7	8.1	3.6	2.5	1.7	2.8	6.9	16.1	22.5
20	15.8	7.8	2.8	2.2	1.7	2.8	7.2	15.6	22.5
21	15.0	6.7	2.8	2.2	1.7	2.8	7.2	17.5	23.1
22	14.5	6.1	1.9	2.2	2.2	2.8	7.2	17.8	22.5
23	14.5	6.1	1.4	2.2	2.2	3.0	7.2	17.8	23.3
24	14.8	5.6	1.7	2.5	2.2	3.3	8.1	18.9	21.9
25	13.3	5.6	1.7	2.5	2.2	3.0	8.9	20.6	23.1
26	12.8	5.3	1.7	2.5	2.2	2.5	8.6	21.7	23.9
27	12.2	5.3	1.7	2.8	2.2	2.5	9.5	23.1	25.3
28	11.9	5.3	1.9	2.5	2.2	2.5	10.0	23.3	25.6
29	11.7	5.3	1.9	2.5	2.2	2.5	10.0	23.1	25.6
30	11.7	4.7	2.2	2.5		2.8	9.5	22.5	25.6
31	11.1		1.9	2.5		2.8		20.8	

Method of Observation.— Generally a sample of water was taken, at the same time, for chemical examination, and in the case of Fresh Pond a (centigrade) chemical thermometer was inserted in the bottle used for the collection of the water. The bottle was sunk to the required point and the stopper withdrawn; after the bottle was filled it was allowed to remain until there was certainty that the mass of the bottle and the thermometer had acquired the actual temperature of the water. The thermometers used were graduated to degrees, and the tenths were estimated; as the thermometers were compared with standards and due correction was made, the error is that due to reading and is probably not much greater than 0°.2 C. in any case, and is generally less than that. Most of the observations in Mystic Pond were made with a Negretti and Zambra "Standard deep-sea thermometer," which was graduated to fifths of a degree centigrade, and *easily* read to tenths. The corrections for this thermometer had been very carefully determined by Mr. S. W. Holman of the Physical Department of the Mass. Institute of Technology. I found that in depths up to seventy-five feet, observations made by the two methods, with proper care, agreed perfectly, although the deep-sea thermometer is very much more convenient and requires much less time.

For aid in the case of Fresh Pond, I am indebted to my former assistants, Mr. Thomas F. Stimpson, S. B., now chemist of the Silver Spring Bleaching and Dyeing Company, Providence, R. I., and Mr. John E. Hardman, S. B., now metallurgist to the U. S. Geological Survey, Rocky Mountain Division. In the matter of Mystic Pond, I was assisted by Mr. W. W. Macfarlane, S. B., now chemist to the Canada Sugar Refining Company, Montreal. For facilities at Fresh Pond my thanks are due to Mr. E. C. Brooks, Engineer at the Pumping Station, and at Mystic Pond to Mr. J. F. Symmes and to Mr. Dexter Brackett, of the City Engineer's Office.

DISCUSSION OF THE OBSERVATIONS.

The general results obtained from the two ponds are quite similar, although the ponds are differently circumstanced in some respects, especially in regard to the relative amount of water received from surface flow and through the ground. During the warmer months, from April to November, a considerable difference in temperature exists between the top and the bottom of the pond and the temperature decreases regularly from top to bottom. It is true that the water which enters at the bottom and sides of the pond is, during this time, colder than the surface water, but this is not the main cause of the difference. The chief cause lies in the fact that water is almost a non-conductor of heat; consequently the upper layers warm up much more rapidly in the spring although, in this climate, at a depth of seventy-five feet the difference between the summer and winter temperature is considerable.

In shallower ponds, in storage reservoirs, and in warmer latitudes we should expect less difference between top and bottom. Thus Mr. Fteley[1] found in one of the storage basins on the Sudbury River, from October 1 to December 20, 1879, almost identically the same temperature at the top and at the bottom where the water was twenty-five feet deep. This is true, in general, of very shallow ponds and of ordinary rivers, also of the shallower portions of even very large lakes. For example, the observations of the U. S. Signal Service (unpublished), made at various points along the shores of the Great Lakes, show almost no difference (and, at some stations, absolutely no difference from the beginning of the year to the end) between the top and bottom temperature at the same time, but the observations are made close to shore, generally from some wharf or pier, and seldom in a depth greater than fifteen feet. Alexander Agassiz found in Lake Titicaca, Peru (Lat. about 16° S., Long. about 70° W.), that " the usual difference between the surface and the bottom, even at the greatest depth (154 fathoms) was not more than from three to four degrees (Fahrenheit). The lowest temperature of the bottom was only 51° (10°.6 C.), the general temperature varying from 54° to 55°; while the surface temperature ranged from 53° to 59°, the greater part of the time 56° to 57° Fahrenheit."[2] These observations were made in February, 1875, when the temperature of the air at midday was from 49° to 97° Fahrenheit.

---

[1] First Annual Report of Mass. State Board of Health, Lunacy, and Charity. Supplement, pp. 121–128 and plate.

[2] Proc. Amer. Acad., XI (1876), pp. 283–292.

While different ponds thus vary from each other, the temperature of the same pond at the same time in different years varies likewise. Thus Table IV contains the record of temperature observations in Fresh Pond at corresponding times of two successive years. The difference between January, 1879, and January, 1880, is very marked, and this might be ascribed to the character of the season. Thus the monthly mean temperatures as observed at the U. S. Signal Office in Boston were, in Fahrenheit degrees, as follows:

TABLE IV. OBSERVATIONS ON FRESH POND.

Date.	Height of Water above Cambridge Datum.	Temperature in centigrade degrees.		
		Two feet from surface.	Eighteen feet from surface.	Thirty-five feet, more or less, from surface.
	Feet.	°	°	°
July 16, 1878 . . .	14.60	25.3	16.8	9.6
July 16, 1879 . . .	14.57	27.2	17.0	11.0
August 20, 1878 . . .	14.67	24.0	20.0	10.2
August 19, 1879 . . .	14.17	21.2	20.8	11.0
January 2, 1879* . .	14.78	0.5	1.0	1.0
January 5, 1880* . .	11.93	2.0	2.3	2.7
January 22, 1879* . .	14.58	0.9	2.0	1.8
January 26, 1880* . .	12.00	2.8	3.0	3.2

* Taken through the ice.

	1878.	1879.
October, . . .	55°.3	56°.6
November, . . .	39°.9	39°.2
December, . . .	29°.6	32°.6
	1879.	1880.
January, . . .	24°.5	35°.0
Mean for four months,	37°.3	40°.8

Difference, 3°.5 F. = 1°.95 C.

The difference between the summer temperature for the two years is, however, not so great. The bottom water was appreciably warmed in 1879, but the monthly mean temperature during the summer, observed as before in Boston and reported in Fahrenheit degrees, were slightly higher in 1878, thus,

	1878.	1879.
June	64.2	64.2
July	72.7	69.9
August . . .	68.1	67.7
Mean for three months	68.3	67.3

As to the manner of freezing.—The observations on these ponds show that the water reaches a uniform, or all but uniform, temperature from top to bottom in the early part of December and that at that time, or shortly after, the temperature is that of the greatest density of water (about 4° C.[1]); thereafter the cooling goes on, the ice forms, and, as soon as the ice becomes strong enough to be safely walked upon, the temperature is found to be very much below 4° C., even at the bottom of the pond. I must confess that I was surprised at the results of the observations on Fresh Pond on January 2, 1879, on finding that the temperature at the bottom was as low as 1°. 0 C.

At that time, I had not succeeded in finding the published record of any observations made through the ice in ponds or lakes, but afterwards the observations of Buchanan on Lochs Lomond and Linlithgow,[2] and those of Forel on the Lakes of Morat and Zurich[3] were published, and I have since found that the fact was noted many years ago by Zadock Thompson[4], who made observations through the ice on Lake Champlain, and gives the following as a sample of his records: "March 27, 1844.—Temperature of the water of the lake in contact with the ice, 32° [0° C.]; six feet below the surface, 32½° [1°.3 C.]; twelve feet below, 34½° [1°.4 C.]; and twenty-five feet below, being the whole depth of the lake at that place, 35½° [1°.9 C.]. These observations were made nearly one-fourth of a mile from the shore and after the lake had been covered with ice about eight weeks." In April, 1851, a few days after the disappearance of the ice, the temperature was found to be 36½° F. (2°.5 C.).

---

[1] The temperature of the greatest density of pure water is generally spoken of as 4° C., but is likely to be a few hundredths of a degree lower. The presence of saline matter, as is well known, lowers the temperature of maximum density, but in the case of our soft pond waters the difference is probably not very great.

[2] Nature, XIX (1879), p. 412.

[3] Comptes rendus, Feb. 16, 1880.

[4] Appendix to Thompson's Natural History of Vermont, 1853. Also Amer. Journ. Sci., (2) XII (1851), p. 22.

Buchanan found that the temperature of the water in Loch Lomond on January 28 and 29, 1879, was 36°.3 F. (2°.4 C.), at the bottom where the depth was sixty-five feet. Forel found in the Lake of Morat a temperature of 2°.7 C. at the lowest depth reached, which was forty meters; in the deeper Lake of Zurich, the temperature increased regularly downward, reaching 3°.9 at one hundred meters, and 4° at one hundred and twenty meters from the surface.

In addition to the observations already mentioned, I have found only one other published set, namely, those made through the ice on Mystic Pond, January 2, 1861, by Henry Mitchell,[1] U. S. Coast Survey. He found a temperature of 36° F. (2°.2 C.) at thirty feet, and 37°.5 (3°.1 C.) at fifty feet from the surface.

It seems, then, to be a fact that the water of lakes and ponds is, as a rule, before freezing, cooled to a temperature much lower than 4° C., not simply at the surface, as generally stated, but to a considerable depth. The commonly received idea and the current statements of the text-books of chemistry and physics are therefore misleading. Thus Roscoe and Schorlemmer[2] say with reference to lakes and rivers, "the temperature of the whole mass is reduced to 4° C., after which the surface water never sinks, however much it may be cooled, as it is always lighter than the deeper water at 4°. Hence ice is formed only at the top, the mass of water retaining the temperature of 4°." Ganot[3] says, after the temperature has reached 4°, "the cooling on the surface still continues, but the cooled layers being lighter remain on the surface and ultimately freeze. The ice formed thus protects the water below which remains at a temperature of 4°, even in the most severe winters, a temperature at which fishes and other inhabitants of the waters are not destroyed."

---

[1] Special Report of the U. S. Commissioners on Boston Harbor, Boston, 1861.

[2] Treatise of Chemistry, London, 1878, Vol. I, p. 224.

[3] Elementary Treatise on Physics, translated by Atkinson. 6th Amer. ed., 1873, p. 247.

I presume that these and similar statements may be traced back to the time of Rumford's experiments on the propagation of heat in liquids. He seems to have believed that the temperature of 4° C. prevailed generally, except in a comparatively thin stratum at the top which was cooled to the freezing point. He even supposed that ground-ice could not be formed in rivers unless they overflowed their banks so as to cover ground already frozen. We know, however, now, that this is not the case, and Rumford himself[1] admits as possible that the temperature of large bodies of water may fall below 4° without freezing at the surface, provided the water is agitated by a strong wind.

I may mention, in this place, that I found on consulting the unpublished observations of the U. S. Signal Service, that the water at the various lake stations is frequently of the temperature of 32° F. (0° C.) *from top to bottom* for several days before the surface is frozen over. At these stations it is true, as before stated, the water is seldom much over fifteen feet deep, but I am informed by Mr. Chesbrough, formerly City Engineer, that in Chicago, on Lake Michigan, the same temperature of 32° F. has been observed from top to bottom at the inlet to the tunnel of the water-works, which is two miles from the shore, where the water is thirty-two feet deep.

In this connection it may be well to correct another wide-spread misconception. It is frequently stated that the water at the bottom of deep lakes, such as those of the Alps, remains at a constant temperature — that of its greatest density — the year around. That the temperature at considerable depths is constant, is approximately true, for the variations, though real, are often only of a few tenths of a degree, but that the temperature is that of the greatest density of the water is not wholly true, because in many deep lakes the temperature of the water at the bottom lies appreciably above that of the greatest density. This has been shown conclusively by various observers, Simony, Fischer-Ooster and C. Brunner, Forel, and others. For instance, Fischer-Ooster and C. Brunner,[1] in their observations on Lake Thun, found that at a depth of four hundred and fifty (Swiss) feet, the temperature varies during the year only between 4°.82 C. and 4°.95 C., not reaching, however, the temperature of the greatest density. Forel[2] has shown that in the Lake of Geneva the temperature, even at a depth of three hundred meters, and during the severe winter of 1879–80, did not fall below 5° C., and that it is extremely doubtful that the water of the open lake has ever reached 4° C. The temperature, however, below one hundred and sixty meters varies only a few tenths of a degree from summer to winter.

---

[1] See Vol. I, p. 320, of the edition of Rumford's Works published by the American Academy, 1870–75.

If a lake has a sufficient depth so that a temperature may be reached which varies only to the extent of a few tenths of a degree, the depth at which such a temperature may be reached, as well as the temperature at the bottom, must depend upon the locality and upon other conditions. Le Conte found[3] a temperature of 4° C. in August, 1873, at the bottom of Lake Tahoe (Lat. 39° N., Long. 120° W.) in a depth of fifteen hundred and six feet (four hundred and fifty-nine meters), but at a depth of seven hundred and seventy-two feet (two hundred and thirty-five meters) the temperature was 5° C., and from this point arose until it reached 19°.44 at the surface.

In the case of our great lakes, the water of which is cool, even in summer, and which are in some winters covered to a considererable extent with ice, it is probable that in summer the bottom water is generally that of the greatest density. To what extent the water of the open lake is regularly or occasionally cooled, I cannot say, as I have not been able to obtain any observations made in winter. Indeed the only reliable observations with the details of which I am acquainted are those made by the U. S.

---

[1] Mem. Soc. Phys. de Genève, XII (1849), pp. 255–276.

[2] Bibl. Univ., Arch. Science, III (1880), p. 505.

[3] Overland Monthly, XI (1873), p. 475.

Lake Survey in Lake Superior which, by the kindness of the Chief of Engineers, U. S. A., I am able to introduce here. See Table V. The instruments employed by the Lake Survey were Casella dee psea thermometers, and the reading of 33°.4 on August 15 is supposed to be erroneous and due to an accidental displacement of the index. The same may be true of the reading 36°.8 on August 18. Omitting these, it would seem that the frequently observed 38°.8 F. (3°.8 C.), in one case 38°.7, is probably the temperature of greatest density of the lake water.

TABLE V. OBSERVATIONS TO DETERMINE SURFACE AND BOTTOM TEMPERATURE OF LAKE SUPERIOR, MADE IN 1871, BY THE U. S. LAKE SURVEY.

Date.	Latitude.	Longitude.	Depth in Fath'ms	Temperature at Surface in deg's Fahr.	Cent.	Temperature at Bottom, in deg's Fahr.	Cent.
August 7	46° 53′	86° 43′	127	56.5	13.6	38.8	3.8
	to	to	129	56.0	13.3	38.8	3.8
	47° 23′	86° 15′	121	53.0	11.7	39.1	3.9
			131	50.1	10.1	38.8	3.8
			74	50.8	10.4	38.8	3.8
August 11	48° 18′	86° 15′	59	55.8	13.2	41.3	5.2
August 15	48° 20′	87° 3′	105	49.7	9.8	39.0	3.9
	to	to	121	49.5	9.7	39.2	4.0
	47° 45′	87° 6′	168	49.2	9.5	39.0	3.9
			116	50.2	10.1	39.3	4.1
			136	52.2	11.2	38.9	3.8
			158	52.9	11.6	33.4?	0.8
August 18	48° 9′	88° 15′	47	51.8	11.0	36.8	2.7
	to	to	129	52.7	11.5	38.9	3.8
	47° 36′	87° 42′	136	52.3	11.3	38.8	3.8
			134	50.1	10.1	38.9	3.8
			82	51.5	10.8	39.0	3.9
August 22	Near Copp	er Harbor.	148	—	—	38.7	3.7
			20	51.3	10.7	39.7	4.3
			61	55.3	12.9	39.2	4.0
August 29	48° 42′	87° 47′	73	55.0	12.8	38.9	3.8

It is very desirable that a more complete study should be made of the temperature of the great lakes at various depths, especially in the cooler parts of the year.

An interesting question arises as to the manner in which the cooling of ponds takes place after the water reaches 4° C. Until that point is reached, the surface water as it cools sinks by virtue of its greater specific gravity, but between 4° and 0° the cooler the water the lighter it is. Various theories have been held in the matter.

Thompson (loc. cit.) supposed that "in consequence of the violent agitation of the water by the cold winds which prevail in the early part of the winter, the whole mass of water is usually cooled down very nearly to the freezing point before any ice forms on the top, and that, after the waters are protected from the winds by a covering of ice, their temperature is gradually raised by the reception of heat from the earth beneath."

Forel,[1] moreover, describes a way in which the action of the wind may cause a very important circulation. He says, "The wind sweeping over the water causes sometimes considerable differences of level; it causes a lowering of the water-level at that portion of the lake which it first reaches, and raises the water at that end toward which the wind is blowing.[2] There results a deep return current, in the direction opposite to that of the wind, and thus a general circulation of the water. In summer this return current takes place at no great depth, because then the water is stratified according to its temperature, and there is considerable difference in density between the water at the surface and at the bottom, but in winter, when the density is uniform throughout the lake, this current can descend very low[3]; consequently, when all the water is at 4°, a violent wind may bring about mechanically a circulation of water throughout the entire body of the lake, even to great depths."

---

[1] Bibl. Univ., Arch. Sci., IV (1880), pp. 89–106.

[2] Forel, F. A. Limnimétrie du Léman, § XIII and § XIX. Bull. Soc. Vaud. Sc. nat. XV (1878), pp. 145 and 408.

[3] During the hurricane of the 20th of February, 1879, fishing nets at Ouchy were torn away and carried for a long distance by this return current, even when they rested on the bottom at a depth of two hundred and three hundred meters. Cf. Chatelanat, Effets sous-lacustres du cyclone du 20 février, 1879. Bull. Soc. Vaud. Sc. nat., XVI (1880), p. 533.

In this same connection, I am informed by Mr. Chesbrough, that at the crib of the Chicago water-works, where the water, as already stated, is thirty-two feet deep, there is at times a difference of 10° F. between top and bottom, especially after a long period of comparatively calm weather; but a single severe storm on the lake will sometimes reduce the difference to one degree or less. Of course, such effects as these must be very much more marked along the shores of a large lake than in a small pond. No doubt this action of the winds is an important cause of circulation. If, however, we compare the observations made in different ponds and lakes, we find that the cooling goes on so regularly and gradually that it does not seem likely that it is dependent upon such an irregular and, if we may use the term, accidental cause.

Buchanan considers that after the temperature of 4° C. has been acquired with tolerable uniformity by the entire mass of water in the pond, cooling takes place more rapidly at the sides of the pond where the ice seems to form first. This cooler and consequently lighter water being unable to balance a column of slightly warmer water of the same height, the cooler water is forced outwards towards the middle of the pond while the warmer water tends towards the edge and thus convection currents are established. Now, no doubt, in the colder months, when the entire mass of the water is nearly of uniform density, slight causes produce a greater amount of circulation than when the water is, as it were, stratified in layers, decreasing in temperature and thus increasing in density from top to bottom. It is probable, also, that the convection currents, supposed by Buchanan, are actually set in motion *to some extent* when the differences in density are as slight as in the cooling from 4° C. to say even 0°. My own observations lead me to believe that in the case of a pond more or less exposed to the wind, and with a moderately steep shore, there is no such marked difference between the temperature of the water at the edge and at the same depth in the centre of the pond, and that, starting from 4°, the temperature of the entire mass of the water may fall considerably before ice forms even at the edge. Of course in very shallow sheltered bays or inlett the temperature of the water may differ to a marked extent from that of the open pond, especially in summer, and in winter ice may form in such a locality while the water outside is much warmer. I have myself observed an instance of a pond,[1] in which the water was in places nearly fifty feet deep, but where there was considerable shallow water, where, although there was much ice on the borders of the pond, the mass of the water was about 4° C. The observations were as follows:

Depth.	Temperature.	
Surface.	3°.9.	Open pond.
12 feet.	4°	At bottom, under the ice.
25 feet.	4°.1.	Open pond.
43 feet.	4°.1.	At bottom.

It seems to me that Buchanan's theory does not suffice by itself to cover all cases, but that in small ponds not much stirred by the winds it may play an important part.

Forel,[2] in admitting both the causes already mentioned as contributing to produce the observed effects, considers the most important action to be that of actual conduction, one layer giving up heat to another until the surface is reached from which the heat is liberated by radiation and by contact with the cooler air.

I am inclined myself to adopt this view of the matter, and to regard conduction as playing the most important part, especially in large and deep bodies of water. This cause would act comparatively slowly, but it would act regularly and would explain satisfactorily the reverse change which takes place in summer where in spite of the warmer water being at the top, the lower layers even to a depth of three hundred meters are warmed up more rapidly than they could be by the mere reception of heat from the earth. It is to be noticed that in the warm months the maximum temperature at considerable depths seems not to be reached until long after the surface temperature has fallen from its maximum. To illustrate this statement take Forel's observations on the Lake of Geneva in 1879.[3]

---

[1] Lake Konomoc, near New London, Conn., Dec. 20, 1879.

[2] Bibl. Univ., Arch. Sci. (1880), pp. 89–106.

[3] Bibl. Univ., Arch. Sci., III (1880), p. 505.

The maximum temperature at a distance of from 0 to 30 meters from the surface was reached in July or August, from 30 to 140 meters the maximum was reached in October, and from 120 to 200 the maximum was not reached until December.

Take also the observations of Fischer-Ooster and C. Brunner on the Lake of Thun. At depths of from 10 to 60 feet the maximum of temperature was reached in September, at 80 feet in October, from 120 to 250 feet in November; at 350 feet the maximum was reached in August, which seems to be exceptional.

It would also seem that, in the case of some ponds which do not freeze in winter, the maximum of temperature is not reached until spring. Thus in the Lake of Thun the minimum seemed to be reached in February at depths from 10 to 80 feet; in March from 120 feet to the bottom, but unfortunately the February was that of 1849 while the March was that of 1848. These observations, although very scanty, would seem to indicate something of the nature of the waves of heat noted in the observations which have been made on ground temperatures.

One fact of general belief which seems, at first sight, to be confirmed by the researches of Forel on the Lake of Morat and by my own observations on Fresh Pond, is that after a coating of ice has once formed there is no further cooling of the water, the cold effecting simply a thickening of the ice-coating. In fact it would seem that the water tends to warm up, or that at any rate, the temperature tends to equalize itself. Thus in 1879, the mean of the temperature at the three different depths in Fresh Pond was on January 2, 0°.8; on January 14, 1°.2, on January 22, 1°.6. Meanwhile the pond fell 0.2 foot, which is equivalent to the loss of about 8,000,000 gallons, but during the same time there were actually pumped about 50,000,000 gallons. Thus the pond received some 42,000,000 of gallons between January 2 and January 22. The bulk of this must have come in as ground-water with a temperature much above that of the pond, but, whether the observed rise of temperature is more or less than would be accomplished by this entrance of ground-water, the data for determining are insufficient.[1]

---

[1] It should be said that in the case of Fresh Pond a large amount of ice is removed as soon as it is thick enough to be of commercial value, so that there is generally more or less open water.

In January, 1880, a similar rise of temperature occurred while the pond was covered with ice. Thus the mean of the three observations made at different depths on January 5, was 2°.3, while on January 26 it was 3°.0. During this interval, the water rose 0.07 foot in spite of the usual pumping, so that a very considerable amount of water must have entered the pond during this time.

If, now, we turn from Fresh Pond, which is known to receive much "ground-water," to Mystic Pond, which is fed mainly by surface-water, we find a different condition of things. In the case of Mystic Pond, it would appear that the cooling continued to an appreciable extent after the ice had formed; thus the mean of the observations taken December 19, 1879, three days before freezing, was 3°.5; the means of the observations taken through the ice were as follows: January 30, 1880, 3°.1; February 6, 2°.4; February 17, 2°.3; February 18, 2°.6. These are the means for the observations at three different depths, but it will be seen (Table II) that the variation is mainly in the surface layer, so that we ought really to consider the surface-water and the deeper water separately.

First, as to the surface-water. From the time of freezing, December 22–23, until the time of the first observation through the ice, January 30, the water was rising rapidly in the pond, but from that time until February 18, the level was nearly constant, and during that time the temperature of the surface-water certainly fell, as appears very clearly in Table III, where we have the daily observations of the water received in the pump-well of the water-works. The bottom of the conduit was, at this time, about ten feet below the surface of the pond. It is to be noted that the bulk of the water enters the main pond at the end furthest from the gate-house through a shallow passage, consequently near the surface; being, most likely, cooler than the mass of water in the pond, it would tend to flow over the surface just under the ice.

If now we consider the water from a depth of eighteen feet to the bottom of the pond, and take the several means of the two observations we have the following: —

December	19	3°.8	Three days before freezing.
January	30	2°.8	
February	6	2 ~~3~~°.9	
"	17	2°.9	
"	18	2°.9	

These figures show conclusively that there was no appreciable warming of the mass of the water after the first observations were made through the ice, and as we, unfortunately, do not know the bottom temperature just after the ice had formed, we are unable to say whether *any* warming of the bottom took place. It would appear that the warming of the water from the heat of the ground and from the entrance of ground-water was counterbalanced by the cooling from above. On this point, I hope to obtain further data myself during the coming winter, but, in any event, a natural pond is not the same thing as a large body of water in an impervious basin. There is generally water entering the pond through the ground, in winter at a higher, and in summer at a lower temperature, and this must influence the temperature of the mass of water to a greater or less extent. In the case of an impervious basin with a constant surface temperature, in contact with the ice, of 0°, we should expect the temperature of the lower layers to fall, owing to conduction upwards to the colder layers and to the ice, if the cooling from 4° to the point at which ice forms is really due to conduction. The whole truth in the matter can hardly be reached except by the accumulation of a considerable number of observations made on different ponds and under different circumstances. The observations most difficult to make at any distance from shore, and the ones which are at the same time of very great value, are those taken the day before ice forms, and those made immediately after the coating of ice has become continuous.

There is one other point on which a larger number of observations is desirable. I refer to the depth to which the diurnal changes of temperature extend under different circumstances. The curves of temperature in Mystic Pond show several times when a few successive days of warm or cold weather produce an effect on the water, even at a depth of seventy-five feet. Note for example, the rise of temperature observed on November 15, 1879, as a result of a week of warm weather. Here the heating up is more marked at the surface, but when there is little difference of temperature at different depths, the temperature sometimes changes to about an equal extent at all depths. Notice, for example, the observations in Mystic Pond, in March, 1880, especially in the early part of the month, when the water was cooling. As a rule, it seems that the diurnal variation below a depth of eighteen feet is very small. On one occasion, June 3, 1879, my assistant, Mr. Macfarlane, spent the whole day on the pond. The results of the observations made are included in Table VI.

TABLE VI. OBSERVATIONS ON MYSTIC POND.

Hour of Day.	Temperature at a depth from the surface of 2 feet.	18 feet.	36 feet.	54 feet.	75 feet.
8.15 A.M. . . .	20.1	19.3	9.2	7.3	6.9
9.15 " . . .	20.3	19.3	—	—	—
10.15 " . . .	20.4	19.3	—	—	—
11.15 " . . .	20.5	19.3	—	—	—
12.15 P.M. . . .	20.6	19.3	—	—	—
1.15 " . . .	20.8	19.3	9.2	7.3	6.9
2.15 " [1]. . .	20.9	19.0	—	—	—
3.15 " [2]. . .	20.9	19.0	—	—	—
4.15 " . . .	20.9	19.0	—	—	—

This table represents the results of a single day's observation. The day was not a very warm one,—the mean daily temperature at Boston was only 14°.3. Of course, in this matter of variation, different ponds would vary very much; in a pond where there is very little difference of temperature from top to bottom we should expect the changes would be felt to a greater extent. In fact I have, through the kindness of Mr. Fitzgerald, Superintendent of the Western Division of the Boston Water-works, the results of observations made by him on Chestnut Hill Reservoir during a day and night. The observations were made with an ordinary (*i. e.*, not self-registering) thermometer inclosed in a copper tube, and are recorded in Table VII.

---

[1] At this time the wind changed and the boat swung to the opposite side of the buoy.

[2] At 6 feet the temperature was 20°.9; at 12 feet, 20°.4.

In concluding this paper, I may say that, while I hope to make further observations on the ponds of this neighborhood during the next year, and eventually on larger bodies of water, I trust that observations may be made by others, especially with reference to the cooling of water from the temperature of greatest density, and to the changes in temperature after the ice has formed.

Table VII. Hourly Observations made on Chestnut Hill Reservoir, Boston Water Works, by D. Fitzgerald, C.E.

Time. 1875.	Temperature (expressed in Fahrenheit degrees)			Temperature (expressed in centigrade degrees)		
	At the surface.	16 feet from surface.	At bottom (24 ft.)	At the surface.	16 feet from surface.	At bottom (24 ft.)
Sept. 1, 9.15 A.M.	72	70	66	22.2	21.1	18.9
10 “	73	71	66	22.8	21.7	18.9
11 “	74	72	66	23.3	22.2	18.9
12 M.	75	72	66	23.9	22.2	18.9
1.10 P.M.	75	72	67	23.9	22.2	19.4
2.5 “	75	71	69	23.9	21.7	20.6
3 “	75	71	69	23.9	21.7	20.6
4 “	75	73	70	23.9	22.8	21.1
5 “	75	72	69	23.9	22.2	20.6
6 “	75	72	69	23.9	22.2	20.6
7.10 “	73	71	69	22.8	21.7	20.6
8 “	74	72	68	23.3	22.2	20.0
9 “	73	72	69	22.8	22.2	20.6
10 “	73	72	70	22.8	22.2	21.1
11 “	73	72	69	22.8	22.2	20.6
12 “	73	72	68	22.8	22.2	20.0
Sept. 2, 1 A.M.	73	72	69	22.8	22.2	20.6
2 “	73	72	70	22.8	22.2	21.1
3 “	72	72	70	22.2	22.2	21.1
4 “	72	72	71	22.2	22.2	21.7

The following list contains such papers on the temperatures of lakes and ponds as have come to the notice of the author, together with indications, in some instances, of the observations recorded. In the present multitude of societies and serial publications, it would be very difficult to make such a list complete. No mention is made of observations on rivers, or of papers on the subject of ground-ice, and a few unpublished series of observations are referred to. All the titles and references have been personally verified, except those designated by a †.

BIBLIOGRAPHY.

Agassiz, Alex. — Hydrographic Sketch of Lake Titicaca. Proc. Amer. Acad., XI (1876), pp. 283-292. [Quoted above.]

Becquerel et Breschet. — Température de la terre et des lacs à diverses profondeurs. Bibl. Univ. de Genève, VII (1837), pp. 173–177.

[Contains a description of an electrical apparatus for determining the temperature at different depths, together with the results obtained in the lake of Geneva. The temperature was found to be 6°.5 at a depth of from 80 to 104 meters.]

Boston, Mass.—Special report of the U. S. Commissioners on Boston Harbor on the relation of Mystic Pond and River to Boston Harbor. Boston, 1861.

[Contains some observations on temperature made on Mystic Pond in September, 1860, and January, 1861, by Henry Mitchell, Assistant U. S. Coast Survey. He found the temperatures as follows:—

	September 1, 1860.		January 2, 1861 (through the ice).	
1 foot.	73° F.	22°.8 C.	32°.75 F.	0°.4 C.
10 feet.	73°.5	23°.1	34°.5	1°.4
20 "	71°	21°.7	—	—
30 "	—	—	36°	2°.2
40 "	62°.5	16°.9	—	—
50 "	—		37°.5	3°.1
60 "	—		36°.5	2°.5
			37°.5	3°.1

Brunner, C. — See Fischer-Ooster.

Buchan, A. — Remarks on the deep water temperatures of Lochs Lomond, Katrine and Tay. Proc. Roy. Geog. Soc., XVII (1873), pp. 73–74; Proc. Roy. Soc. Edinb., VII (1869–72), pp. 791–795; Br. Assoc. Rep., XLII (1872), pp. 207, 208 (Sect.)

[The author alludes to the observations of Sir Robert Christison on the deep water temperature of Loch Lomond in 1871, and to those made by James Jardine, C. E., in Lochs Tay, Katrine and Lomond in 1812 and 1814. He finds that the mean temperature of the air for the six colder months is almost the same as the deep water temperature of the lochs, and suggests that "it is the mean temperature of the cold half of the year which determines the temperature of the lowest stratum of water at the bottom of deep lakes."]

Buchanan, J. Y. — On the freezing of lakes. †Proc. Roy. Soc. Edinb., X (1879–81), pp. ?—?; Nature, XIX (1878-79), pp. 412–414. [Quoted above.]

Burnier.— Résumé des observations sur la température du Lac Léman. Bibl. Brit. Arch. Sci., XXI (1852), pp. 192, 193.

[Observations made at Morges, at depth of 1 meter.]

CHRISTISON, Sir ROBERT. — Address at opening session of the Royal Society of Edinburgh, November 27, 1871. Proc. Roy. Soc. Edinb., vii (1869–72), pp. 531–574.

[The address contains (pp. 567–574) the results of some observations on temperature made on various Scotch lochs. The following are the observed temperatures at top and bottom; the decrease from the surface was perfectly regular.

St. Mary's Loch,	June 12–18, 1871.	Surface	56° F.	
" "	" " "	150 feet		46° F.
" "	September 8, "	Surface	55°	
" "	" " "	144 feet		47°
Loch Lomond,	October 11, "	Surface	52°	
" "	" " "	400–618 feet		41°.8
" "	" 12, "	Surface	52°	
" "	" " "	300–518 feet		42°
" "	November 18, "	Surface	46°	
" "	" " "	270–610 feet		42°
" "	April 10, "	Surface	43°	
" "	" " "	200–574 feet		42°
" "	May 6, "	Surface	44°.5	
" "	" " "	300–574 feet		42°.1

The observations, on and after November, were made with a protected Casella thermometer, those previous to that time with a Six's thermometer.]

DE LA BECHE, H. T. — Sur la profondeur et la température du Lac de Genève. Bibl. Univ. Sci. et Arts, xii (1819), pp. 118–126; Edinb. Phil. Journ., ii (1820), pp. 107–110; Ann. de Chim., xix (1821), pp. 77-83; Gilbert Ann., lxvi (1820), pp. 146-151.

[Observations made September, 1819. He found the temperature from 40 to 70 fathoms, to be 44° F.; from 80 fathoms down, 43°.5 F. The thermometer used was not protected against pressure.]

DE LA BECHE. — Sur la température des lacs de Thun et de Zug en Suisse. Bibl. Univ. Sci. et Arts., xiv (1820), pp. 144, 145; Gilbert Ann., lxvi (1820), pp. 151–152.

[The temperature in Lake Thun was found to be 41°.5 F. from 50 to 105 fathoms; in Lake Zug, 41° from 25 to 38 fathoms.]

DEWEY, CHESTER. — On the temperature of Lake Ontario. Amer. Journ. Sci., xxxiii (1838), pp. 403–405; xxxvii (1839), pp. 242, 243.

[Record of observations of surface temperature at various points in a line across the lake from shore to shore.]

FISCHER-OOSTER, C. de, et C. BRUNNER. — Recherches sur la température du Lac de Thoune. Mém. Soc. Phys. et Hist. nat. Genève, xii (1849), pp. 255-276, where the name is printed Fischer-Foster; Bibl. Univ. Arch. Sci., xii (1849), pp. 20-39; † Annuaire météor. de France, 1850, pp. 268-274.

[Contains observations at twelve various depths, from 10 to 550 feet, made March 23, May 13, July 3, August 5, September 6, October 28, November 26, 1848, and February 3, 1849. The observations were made by fastening a number of slowly acting thermometers, duly protected, at intervals, on one line and allowing them to remain over night in the lake. In the morning the line was drawn rapidly in and the thermometers read quickly as they appeared at the surface. This is one of the most complete series of observations on any of the Swiss Lakes.]

Forel, F. A. — Introduction à l'étude de la faune profonde du Lac Léman. Bull. Soc. Vaud., x (1869), pp. 217-223.

[Contains a review of some of the earlier observations on temperature in the Swiss lakes.]

Forel, F. A. — Nouvelle méthode de sondage thermométrique. Bull. Soc. Vaud., xiii (1874), pp. 38-45.

Forel, F. A. — La température des lacs gelés. Comptes rendus, xc (1880), pp. 322-324.

[Contains the results of observations through the ice on the Lake of Morat and the Lake of Zurich, and has been quoted above.]

Forel, F. A. — La congelation des lacs suisses et savoyards pendant l'hiver 1879-1880. L'Echo des Alps, Nos. 2 et 3, 1880.

Forel, F. A. — Températures lacustres. Recherches sur la température du Lac Léman et d'autres lacs d'eau douce. Bibl. Univ. Arch. Sci., (3) iii (1880), pp. 501-516; iv (1880), pp. 89-106.

[This has been quoted above.]

Fteley, A. — Algae observed in storage-basin No. 3, of the Boston Water Supply, 1879. First Annual Report of the Mass. State Board of Health, Lunacy and Charity, 1880. Department of Health, pp. 121-128 and plate.

[Contains also observations on the temperature at top and bottom of pond and has been quoted above.]

Geneve. — Sur les circonstances qui ont accompagné le gel du Lac de Genève, le 15 fevrier, 1854. Verh. d. Schw. naturf. Gesellsch., 1854 p. 92.

[The Lake of Geneva has never been completely frozen as far as known. The lower end near Geneva was frozen February 22, 1810, February 23 and 24, 1814, February 3 and 8, 1830, and February 15, 1854. The conditions are a very low temperature for a long time, followed by a strong wind from the North-east, or "*bise*," etc.]

Indiana. — Seventh Annual Report of the Geological Survey made during the year 1875, pp. 469-495. Observations on the depth and temperature of some of the lakes of Northern Indiana, by G. M. Levette.

[The observations extended over thirteen lakes varying in depth from 10 to 78 feet. The temperatures were taken with a Miller-Casella deep sea thermometer; the dates were not given but it would seem that the work was done in the month of August. The surface temperature varied from 60°F., to 69° F., and the lowest temperature, 46°.5, was in Eagle Lake, at a depth of 78 ft. As the ponds freeze in winter, the temperature must be subject to continual variation, and a single undated observation has but a limited value in this particular connection.]

JARDINE, JAMES. — Observations on the deep-water temperature of Lochs Tay, Katrine and Lomond. Quoted by Buchan (Roy Soc. Edinb., VII (1869-72), p. 794), also in † Leslie's article on "Climate" in the older editions of Encyclopaedia Britannica, also in †Leslie's Treatises on various subjects of natural and chemical philosophy. Edinburgh, 1838.

Loch Tay,	August	12,	1812.	Surface	57°.2 F.	
" "	"	"	"	420 feet		41°.9 F.
Loch Katrine,	September	7,	"	Surface	57°.9	
" "	"	"	"	210–360 feet		41°.5
" "	"	"	"	480 feet		41°.4
" "	"	8,	1814.	Surface	56°.8	
" "	"	"	"	480 feet		41°.4
Loch Lomond,	"	8,	1812.	Surface	59°.5	
" "	"	"	"	540–600 feet		41°.5

JOLLY, PH. — Bathometer und graphische Thermometer. Münch. Sitzungsber., 1862, pp. 248-280.

[Contains a description of instrument employed and results of observations on the Königsee, Obersee and Walchensee, in August 1862, at various depths. The results were afterwards criticised by Simony and doubt thrown on the reliability of the instrument.]

JOLLY, PH. — Temperaturbestimmungen in der Tiefe einiger baierischen Gebirgsseen. Pogg. Ann., CXXII (1864), pp. 659-660.

[This is the same as the last part of previous paper.]

KOPP. — Température du Lac de Neuchâtel. Bull. Soc. Sci. nat. Neuchâtel, VI (1861-64), p. 247. (See Neuchâtel.)

LADAME, H. — Note sur la température du lac à différentes profondeurs. Bull. Soc. Sci. nat. Neuchâtel, V (1859-61), pp. 743-761.

[Record of observations made in the Lake of Neuchâtel by Professor Ladame at various depths down to 90 feet on the following dates,—June 21, July 6, July 11, 1839, and October 1, 1840. The instrument employed was an alcohol minimum thermometer not encased. Observations were also made by Professors Ladame and Guyot on February 22 and April 14, 1842, to a depth of 180 and 276 feet, using a thermométrographe inclosed in a thick copper tube. The observations of February 22 are quoted above. The paper contains also a discussion of the manner in which heat is propagated in the lake.]

LADAME, H. — Expériences faites pendant huit ans sur la température du Lac de Neuchâtel. Actes Soc. Helvét. Sci. nat., 1855, pp. 38-39, 213.

[Comparison of the mean surface temperature of the lake with the mean temperature of the air.]

LeConte, John.—Physical Studies of Lake Tahoe (in press). Abstract of results of observations in Overland Monthly, xi (1873), p. 475. [Quoted above.]

Levette, G. M. — See Indiana.

† Millet. Température des lacs. † Cosmos, —, pp. ?——?

Milner, J. W.— See United States Fish Commission.

Neuchatel. — Observations are apparently made daily of the surface water, but seem not to be published in detail. Résumés may be found in the Bulletin Soc. Sci. nat. de Neuchâtel as follows: for 1856, in Vol. iv, pp. 250, 252; for 1857, iv, p. 429; for 1858, v, p. 141; for 1859, v, pp, 310, 311; for 1860, v, p. 752; for 1861, vi, p. 247. The publication of the résumé seems to be interrupted after 1861. [Observations interrupted?] Prof. Hirsch announced in Vol. x, p. 29, that daily observations of the temperature of the water had been made since January 1, 1874.

Rumford, Count. — On the propagation of heat in fluids. Essay vii. Rumford's Works, Ed. Amer. Acad., i, p. 321.

[Rumford alludes to de Saussure's observations on the Swiss Lakes and holds that the bottom temperature is about that of the maximum density of water, throughout the year.]

† Saussure, H. B. de.— Voyages dans les Alpes, Genève, 1789, pp. 18-34. † Ann. de Chim. v (1817), p. 403 (footnote).

Schlagintweit-Sakuenluenski, H. v. — Ueber die Temperatur von Alpenseen in grossen Tiefen nach Beobachtungen im Starnbergersee und im Chiemsee. Münch. Sitzungs., 1867, pp. 305-316.

[The observations on the Starnbergersee were made June 23, 1866. The temperature at the bottom (406 Bav. ft. = 118.5 meters) was 3°.45 C., which experiment showed it to be the temperature of greatest density of the water at the bottom. The observations on the Chiemsee were made September 17, 1866. The bottom temperature (273 Bav. ft. = 79.8 meters) was 7°.1 C.]

Schmidt, J. T. J. — Wassertemperaturen in Attika, Böotien, Megaris und Euböa. Peterm. Mittheil. 1862, pp. 333.

[Contains only one surface observation on Lake Hylike, May 22, 20°.9 C.]

Silliman, B. — Circumstances connected with the formation of ice in still waters and with the continued action of cold on the fluid beneath. Amer. Journ. Sci., (1) iii (1821), pp. 179-182.

[Of no consequence in this connection.]

Simony, F.— Die Seen des Salzkammergutes. Wien. Sitzungsber. iv, i (1850), pp. 542-566. Full abstract in Fortsch. d. Physik, vii (1851), pp. 1013-1019.

[This paper contains a circumstantial account of the extent, depth and general character of the various lakes together with numerous observations of temperature. A minimum thermometer was employed which was not protected against pressure. The results obtained at the surface, and at the bottom, were as follows. The depth is given in Vienna feet, the temperature in Reaumur degrees.

Traunsee,	August	30,	1848.	Surface	14°.4 R.	
“	“	“	“	500–600 feet		3°.5 R.
Attersee,	September	2,	“	Surface	14°.8	
“	“	“	“	300–500 feet		3°.4
Mondsee,	“	3,	“	Surface	15°.6	
“	“	“	“	200 feet		3°.5
Ober. Wolfgangsee,	“	4,	“	Surface	14°.5	
“ “	“	“	“	300–350 feet		3°.5
Unter. Wolfgangsee,	“	“	“	Surface	15°.0	
“ “	“	“	“	200 feet		4°.0
Ober. Hallstätter See,	“	6,	“	Surface	12°.0	
“ “ “	“	“	“	200–350 feet		3°.5
Unter. “ “	“	“	“	Surface	12°.1	
“ “ “	“	“	“	100 feet		4°.6
Grundelsee,	August	27,	“	Surface	15°.1	
“	“	“	“	200 feet		3°.6
Toplitz See,	“	“	“	Surface	14°.1	
“ “	“	“	“	100–300 feet		4°.6
Altausseersee,	“	18,	“	Surface	12°.9	
“	“	“	“	60–150 feet		3°.8
Vord. Gosausee,	“	20,	“	Surface	12°.6	
“ “	“	“	“	175–200 feet		3°.8
Hint. Gosausee,	“	“	“	Surface	12°.2	
“ “	“	“	“	125 feet		3°.3

This paper also contains the results of observations on the Hallstätter See, in 1849, on April 19 and 27, May 4, 11 and 25, August 31 and November 5, as well as a general discussion of the matter of lake temperatures.]

† Simony, F. — Die Seen der Alpen. Oester. Revue, 1864, i, p. 186.

† Simony, F.—Die Seen des Traungebietes. Oester. Revue, 1864, v, p. 190. Zeitschr. für Erdkunde, (2) xvii (1864), pp. 239-243.

† Simony, F. — Beobachtungen über Temperaturen und Wasserdruck in grösseren Seetiefen (Alpenseen) während d. Jahre 1868 und 1869. Arch. für Seewesen, 1870, p. 205.

Simony, F. — Ueber Temperatur und Tiefenverhältnisse des Königsees. Wien. Sitzungsber. (Math-Nat. Classe), lxix, ii (1874), pp. 655-676. † L'Institut, ii (1874), p. 317. Full abstract in Fortschr. d. Phys. xxx (1874), pp. 1259-1264.

[Observations on October 19, 1873, showed a regular decrease in the temperature from the surface (11°.80 C), to a depth of 200 ft. (Vienna). From 200 ft. to the bottom, 590 feet, the temperature was 4°.55. These observations do not agree with those obtained by Jolly (Münch. Sitzungsber., 1862, ii, pp. 248-280), and doubt is thrown upon the reliability of Jolly's batho-thermometer. The paper also contains a table showing the observations made at different times, on various lakes of the Traungebiet. Some of the results are as follows:

Attersee,	October 6, 1873.	5 feet	15°.60	
“	“ “ “	200–500 feet		4°.55 R.
Gmundner See,	“ 17, “	5 feet	12°.85	
“ “	“ “ “	500–600 feet		4°.75
Offensee,	“ 11, “	5 feet	12°.70	
“	“ “ “	100 feet		5°.55
“	“ “ “	114 feet		5°.25
Vorderer Langbathsee,	“ 12, “	5 feet	13°.80	
“ “	“ “ “	80 feet		5°.50
“ “	“ “ “	100 feet		5°.30
Hinterer Langbathsee,	“ “ “	5 feet	10°.70	
“ “	“ “ “	40 feet		7°.25
“ “	“ “ “	60 feet		6°.95
Almsee,	“ 14, “	5 feet	8°.50	
“	“ “ “	20 feet		6°.25
Toplitz See,	September 12, 1868.	5 feet	15°.00	
“ “	“ “ “	60–300 feet		5°.55
Grundel See,	“ 13, “	5 feet	16°.70	
“ “	“ “ “	150–200 feet		4°.55
Hallstättersee,	“ 28, “	5 feet	13°.85	
“	“ “ “	300–400 feet		4°.45
Vorderer Gosausee,	August 28, 1870.	5 feet	10°.40	
“ “	“ “ “	100–200 feet		4°.65
Schwarzensee,	“ 30, “	5 feet	13°.70	
“	“ “ “	80–150 feet		3°.95
Fuschlsee,	“ 31, “	5 feet	14°.00	
“	“ “ “	150 feet		4°.65
“	“ “ “	200 feet		4°.56
Wolfgangsee,	September 1, “	5 feet	14°.80	
“	“ “ “	300 feet		4°.25

SIMONY, F. Ueber die Grenzen des Temperaturwechsels in der tiefsten Schichten des Gmundner Sees und Attersees. Wien. Sitzungsber., LXXI, I (1875), pp. 429-440. Abstract in Fortschr. d. Physik, XXXI (1875), pp. 983–984.

[Observations on the Gmundner See, September 25, 1875, showed a regular decrease of temperature from the surface to the bottom; the temperature at the surface was 16°.50 C., at depths of from 400 to 604 feet, the temperature was 4°.63. On April 10‘ 1875, it varied,

at from 5 to 30 feet between 3°.80 and 3°.90 C.
“ “ 40 to 100 “ 4°.00 and 4°.10

At 125 feet the temperature was 3°.80, and thence increased slowly, being 3°.95 from 500 to 604 feet from surface. The bottom temperatures for several years (1868-1875), are compared with the temperature of the air for the Winter and Summer periods. In the Attersee the temperature, September 21, 1874, decreased regularly from the surface (16°.90), to a depth of 300 feet; from 300 to 540 feet the temperature was 4°.35. On April 11, 1875, the temperatures were, at surface, 8°.60; from 10 to 125 feet, 3°.50-3°.55; from 150 to 300 feet, 3°.60-3°.65; from 400 to 540 feet, 3°.70. The author employed a Casella deep-sea thermometer, and also another thermometer of peculiar construction.]

Struve, H. — Kurzer Bericht über eine Reise auf dem Ladogasee Bull. St. Pétersb. vii (1864), pp. 510-515.

[Observations on Lake Ladoga made in June, 1864, showed on two different days the following temperatures, the air temperature being in the second instance 8°.5 C., in the first instance not given.

Surface	4°.0 C.	Surface	3°.2
Bottom, 474 ft.	3°.8	Bottom, 672 ft.	3°.8

Thompson, Z. — Sudden disappearance of ice on Lake Champlain. Amer. Journ. Sci. (2) xii (1851), p. 22.

[Observations of temperature made through the ice, quoted above.]

United States Fish Commission. — Observations made by J. W Milner on Lake Michigan are alluded to in the Report for 1872-73, p. xv.

United States Lake Survey.—Observations were made in 1871 on Lake Superior. The results are briefly alluded to in the Report of the Chief of Engineers, 1871, p. 1021, and have been quoted above. Allusions are made to earlier observations in the Report of Superintendent of Lake Survey, 1860.

United States Signal Service.—Daily observations on temperature are made at the following lake stations: Alpena, Buffalo, Burlington, Chicago, Detroit, Duluth, Escanaba, Grand Haven, Marquette, Milwaukee, Toledo. The observations are made at top and bottom, but in shallow water. The observations are not published in detail, but monthly maxima and minima are given on the monthly weather map, No. ii, and, in the Report of the U. S. Fish Commissioner for 1875-76, pp. 851-861, there are tables of observations from March, 1874, to February, 1875, and from March, 1876, to February, 1877, inclusive.

Zerrenner, C. — Beobachtungen über Gewässer-Temperaturen. Jahrb. d. geol. Reichsanst., iv (1853), pp. 492-493.

[Observations of surface temperature on several lakes of Southern Bavaria, the Tyrol and Northern Italy.]

OBSERVATIONS OF TEMPERATU

IN

MYSTIC LAK

BY WM. RIPLEY NICHOLS.

——————— 2 feet from surface.
—·—·—·— 18 feet from surface
- - - - - - - 75 feet from surface.
··············· at Pumping station

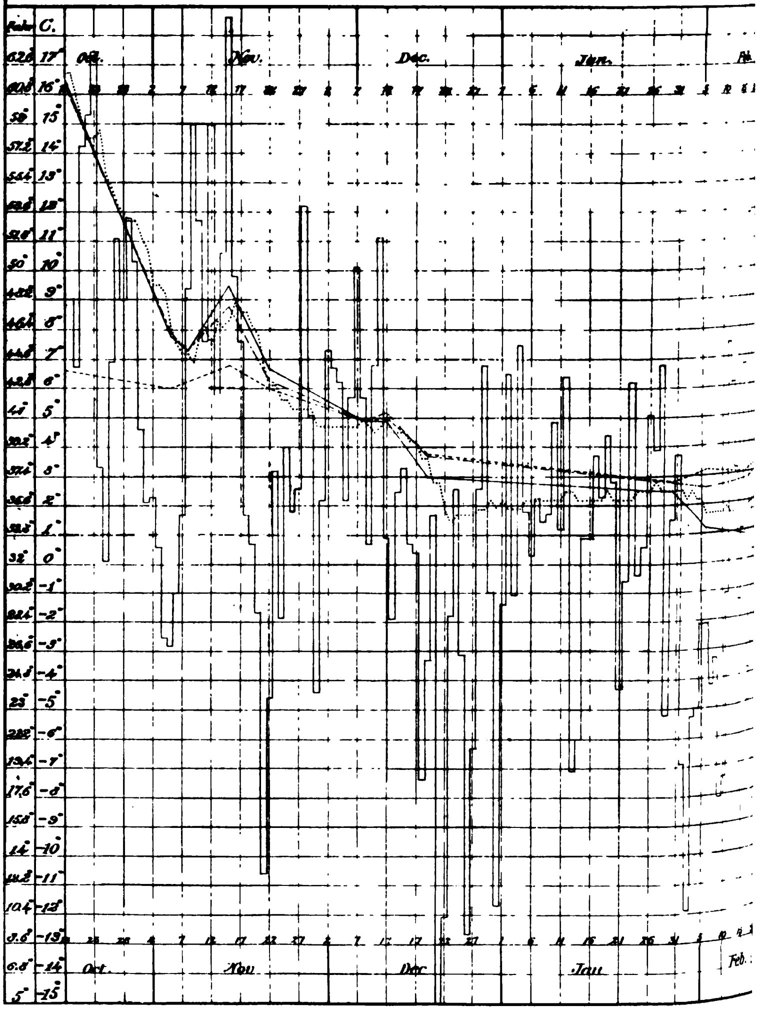
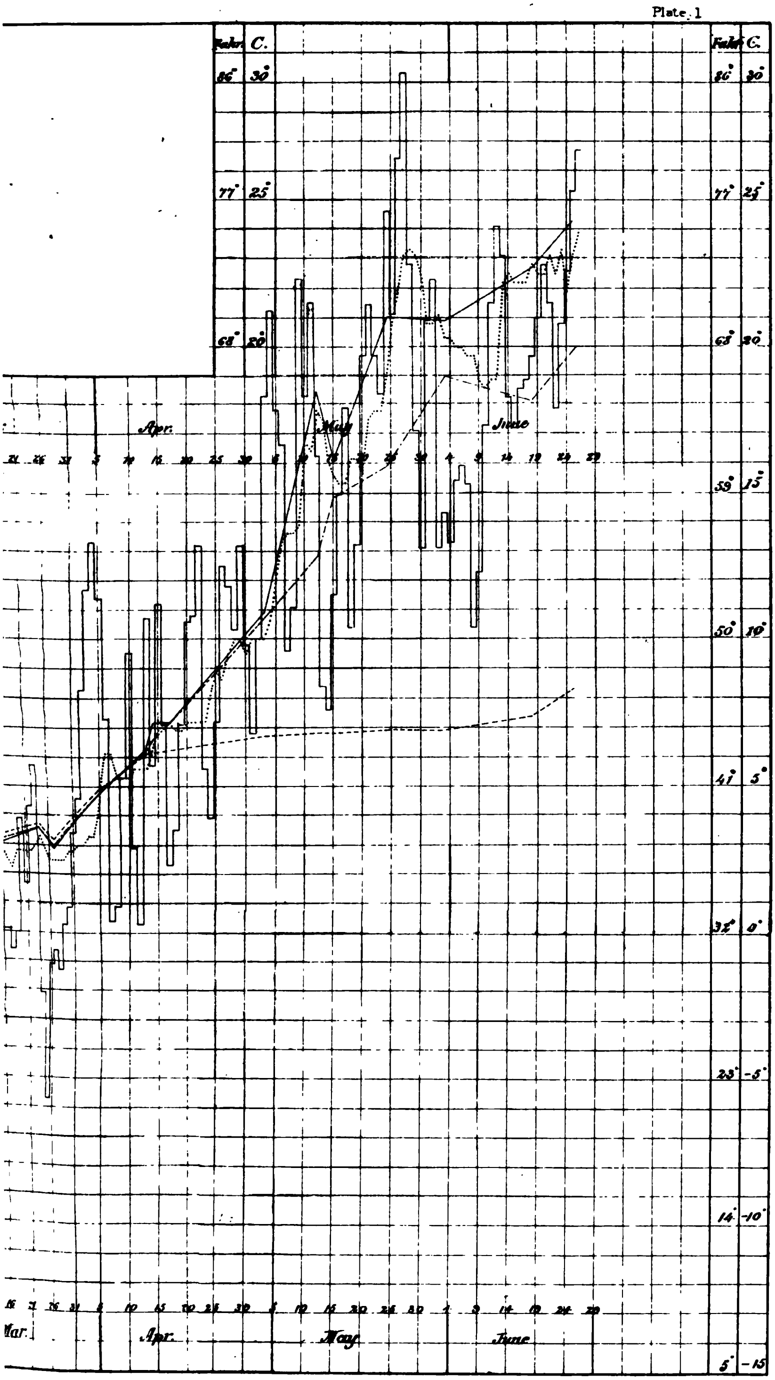


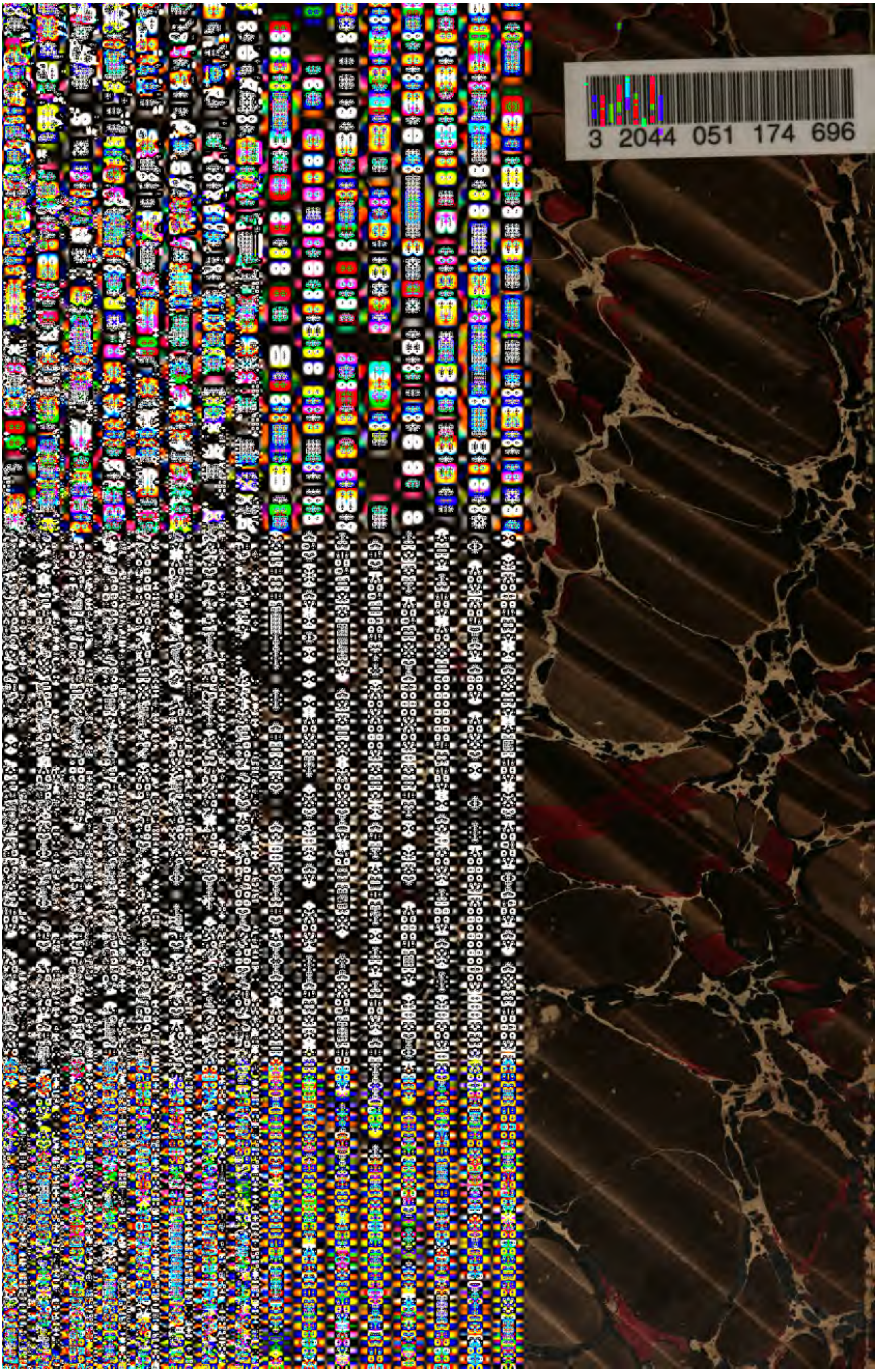
Plate 1



The Heliotype Printing Co. 211 Tremont St. Boston.

RY

3 2044 051 1



3 2044 051 174 696